

AD _____

Award Number: DAMD17-01-1-0042

TITLE: TRAIL: A Novel Therapeutic Agent for Prostate Cancer

PRINCIPAL INVESTIGATOR: Honglin Li, Ph.D.

CONTRACTING ORGANIZATION: Children's Memorial Hospital
Chicago, IL 60614

REPORT DATE: May 2003

TYPE OF REPORT: Annual

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

DISTRIBUTION STATEMENT: Approved for Public Release;
Distribution Unlimited

The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision unless so designated by other documentation.

20030902 100

REPORT DOCUMENTATION PAGE

*Form Approved
OMB No. 074-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503

| | | |
|--|--|--|
| 1. AGENCY USE ONLY (Leave blank) | 2. REPORT DATE May 2003 | 3. REPORT TYPE AND DATES COVERED Annual (15 Apr 2002 - 14 Apr 2003) |
| 4. TITLE AND SUBTITLE TRAIL: A Novel Therapeutic Agent for Prostate Cancer | | 5. FUNDING NUMBERS DAMD17-01-1-0042 |
| 6. AUTHOR(S) Honglin Li, Ph.D. | | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Children's Memorial Hospital Chicago, IL 60614 | | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| E-Mail: | | |
| 9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Medical Research and Materiel Command Fort Detrick, Maryland 21702-5012 | | 10. SPONSORING / MONITORING AGENCY REPORT NUMBER |
| 11. SUPPLEMENTARY NOTES | | |
| 12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for Public Release; Distribution Unlimited | | 12b. DISTRIBUTION CODE |
| 13. ABSTRACT (Maximum 200 Words) This study aims to elucidate the signaling pathway of TRAIL-mediated apoptosis in prostate cancer cells, and to examine the therapeutic effect of TRAIL on prostate cancer cells in vitro and in vivo. We found that most of prostate cancer cells such as androgen-independent PC-3 and DU145 cells are sensitive to TRAIL treatment while normal prostate epithelial cells are resistant. This result indicates that TRAIL may be appropriate agent for treatment of late-stage prostate cancer with no cytotoxicity to normal prostate cells. Further investigation on the molecular mechanism of TRAIL resistance revealed that pro-survival protein kinase Akt existed in a constitutively active form at high level in LNCaP cells that are resistant to TRAIL. Inhibition of PI 3-kinase sensitized LNCaP cells to TRAIL, suggesting that Akt may play a critical regulatory role in TRAIL signaling. To further understand the working mechanism of Akt, we surveyed its downstream targets, and found that the elevated eNOS activity by Akt phosphorylation may partially contribute to Akt-mediated TRAIL resistance in LNCaP cells. Overexpression of eNOS in PC-3 cells prevents TRAIL-induced apoptosis. | | |
| 14. SUBJECT TERMS Prostate cancer; apoptosis, TRAIL, signaling pathway, caspase, Bcl-2 | | 15. NUMBER OF PAGES 40 |
| | | 16. PRICE CODE |
| 17. SECURITY CLASSIFICATION OF REPORT Unclassified | 18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified | 19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified |
| | | 20. LIMITATION OF ABSTRACT Unlimited |

Table of Contents

| | |
|--|----------|
| Cover..... | 1 |
| SF 298..... | 2 |
| Table of Contents..... | 3 |
| Introduction..... | 4 |
| Body..... | 4 |
| Key Research Accomplishments..... | 8 |
| Reportable Outcomes..... | 8 |
| Conclusions..... | 9 |
| References..... | 9 |
| Appendices..... | |

INTRODUCTION:

Apoptosis or programmed cell death is a cell intrinsic suicidal mechanism, which is essential for tissue homeostasis and animal development. Dysregulation of this process may lead to a number of human diseases, including prostate cancer (PC). Resistance of PC cells to apoptosis plays important roles in the pathogenesis and progression of prostate cancer. Some of androgen-independent cancer cells that do not undergo apoptosis after androgen ablation become apoptosis-resistant and metastatic, frequently due to upregulation of anti-apoptotic Bcl-2 and loss-of-function of p53 (Bookstein et al, 1993; Eastham et al, 1995; Cardillo et al, 1997). As a result, metastatic prostatic cancer, usually resistant to conventional anti-tumor therapies, is a lethal disease without curative therapy. Therefore, an understanding of apoptotic machinery and its regulatory mechanism in PC cells is critical for us to develop an effective therapy to combat metastatic prostate cancer. The TNF-related apoptosis-inducing ligand, TRAIL (also called Apo2L), has recently been emerging as a non-toxic anti-cancer agent because it is capable of inducing apoptosis in many of tumor cell lines but not in normal cells tested (Wiley et al, 1995; Pitti et al, 1996). In this project, we will examine the effects of TRAIL treatment in androgen-dependent and -independent PC cells, to dissect the TRAIL-induced signaling pathway in those cell lines, and to characterize the synergistic effects of TRAIL with other therapeutic agents, and finally to test the anti-tumor effect of TRAIL in the animal models of prostate cancer. Through these works, we will be able to firmly establish the foundation for a novel therapy of prostate cancer.

BODY:

Task 1: To examine the TRAIL-induced apoptotic pathway in prostate cancer cells (months 1-12):

- a. To survey TRAIL sensitivity of PC cancer cells (months 1-6)
- b. To examine the effect of cycloheximide on TRAIL sensitivity of prostate cancer cells (months 6-9)
Please see the report of year 2002.
- c. To identify the possible molecular determinants of TRAIL sensitivity (month 6-12)

We have continued to work on this project and combined previous and current results together.

Results:

To identify the possible molecular determinants of TRAIL sensitivity, we have screened the known regulators for TRAIL signaling pathway.

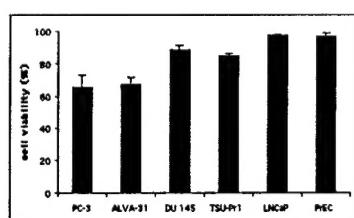
1) Effect of TRAIL on human prostate normal and cancer cells

Recombinant human TRAIL (residues 95-281) was produced in *Escherichia coli* as a fusion protein containing an N-terminal His-tag, and purified by using standard nickel affinity chromatography. Cytotoxic effects of TRAIL on human prostate normal epithelial cells (PrEC) and cancer cell lines (namely, PC-3, TSU-Pr1, DU 145, ALVA-31 and LNCaP) were evaluated by MTT assay. As shown in Figure 1A, PC-3 and ALVA-31 cells were sensitive to TRAIL, and DU 145 and TSU-Pr1 revealed moderate sensitivity, while LNCaP and normal PrEC cells were fully resistant to TRAIL treatment.

2) Expression of TRAIL receptors and pro-apoptotic proteins in prostate cancer cells

As shown in Figure 1, no correlation was found between the TRAIL sensitivity and the expression of TRAIL receptors, and Bax/Bak.

A.



B.

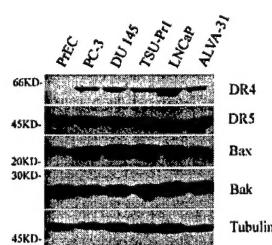


Figure 1. Effect of TRAIL on cell viability of human prostate normal and cancer cells. A. The effect of TRAIL on cell viability. Cells were treated with TRAIL (500ng/ml) for 24 h, and viability was measured by MTT assay. Data represent mean \pm S.E. B. Expression of TRAIL receptors and pro-apoptotic proteins in prostate cancer and normal cells. Cell lysates prepared from prostate normal and cancer cells were probed by immunoblotting with anti-DR4, anti-DR5, anti-Bax, and anti-Bak antibodies.

2) LNCaP Cells expresses high levels of active Akt and eNOS protein

Previous studies have demonstrated that LNCaP cells have a high level of constitutive active Akt due to the deletion and mutation at PTEN alleles (Thakkar et al, 2001). Inhibition of PI3K activity using wortmannin and LY-294002 suppresses constitutive Akt activity and sensitizes LNCaP cells to TRAIL. Conversely, overexpression of constitutively active Akt attenuates TRAIL-induced apoptosis (Nesterov et al, 2001; Thakkar et al, 2001). By repeating these experiments, we found that there was no PTEN expression in LNCaP cells, in which the highest Akt activity was observed, although total Akt protein levels among these prostate cancer cells were similar (Fig. 2). Another interesting substrate is eNOS, whose activity is enhanced when modified by Akt (Dimmeler et al, 1999; Fulton et al, 1999). To explore whether eNOS may be involved in TRAIL-resistance, we examined the expression of three isoforms of NOS among the five prostate cancer cells. As shown in Fig. 2, only LNCaP cells expressed eNOS, whereas all of them expressed nNOS, but do not express iNOS.

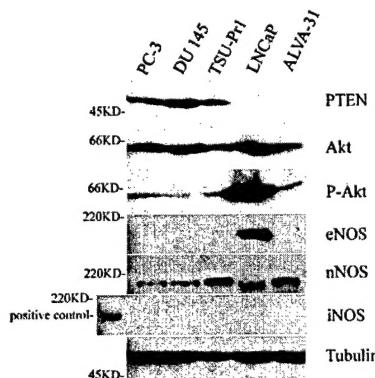


Figure 2. LNCaP cells express high level of eNOS. Cell lysates from five prostate cancer cell lines were probed by immunoblotting with anti-PTEN, anti-Akt, anti-phospho-Akt, anti-nNOS, anti-iNOS and anti-eNOS.

3) NOS inhibitor sensitized LNCaP cells to TRAIL-induced apoptosis

To further examine whether the high-level expression of eNOS in LNCaP cells contributes to TRAIL resistance, we used eNOS inhibitor to test if inhibition of eNOS can sensitize LNCaP cells to TRAIL. L-NIO is a potent inhibitor of eNOS compared to other arginine analogs (Rees et al, 1990). LNCaP cells were pre-treated with L-NIO for 2 h before exposure to TRAIL (500ng/ml), and cell death was evaluated by nuclear morphology and measured by MTT assay after 24 h treatment. As shown in Fig. 3A and 3B, TRAIL or L-NIO alone did not induce any cell death (2% cell death), but pretreatment with L-NIO or protein synthesis inhibitor (cycloheximide) sensitized LNCaP cells to TRAIL-induced apoptosis (38% and 76% cell death, respectively).

4) eNOS expression partially inhibits TRAIL-induced apoptosis of PC-3 cells

To further test this possibility, we used PC-3 cells as a model system to test the effect of eNOS on TRAIL-induced apoptosis, because PC-3 cells were most sensitive to TRAIL among the five prostate cancer cells we tested (Fig. 1A) and have no expression of eNOS (Fig. 2). Wild type eNOS and mutant eNOS (S1177D) (Mutation of serine 1177 into aspartic acid that substitutes for the negative charge afforded by the addition of phosphate and mimics the activation state induced by Akt) were introduced into PC-3 cells by gene transfection, and stable clones were selected. We randomly selected 30 G418-resistant clones, among which 6 clones expressed wild-type eNOS and 4 clones expressed eNOS (S1177D), respectively (Fig. 4A). The clones with high-level expression of eNOS were tested for their

TRAIL sensitivity. Cells were treated with TRAIL (500ng/ml) for up to 24 h, and the DNA content was analyzed by flow cytometry. The sub-G₁ DNA peak, characteristic of apoptotic cell death, was clearly detectable in PC-3 cells (8.6%±0.3%) or empty vector clones (10.0%±0.7%) treated with TRAIL with respect to untreated controls, while eNOS-expressing cells have much lower sub-G₁ peak (5.2%±0.3%), and the lowest sub-G₁ peak was observed in eNOS (S1177D)-expressing cells (2.4%±0.1%) (Fig. 4C). These results demonstrated that overexpression of eNOS in TRAIL sensitive PC3 cells can inhibit TRAIL-induced apoptosis, further indicating the role of eNOS in regulation of TRAIL signaling.

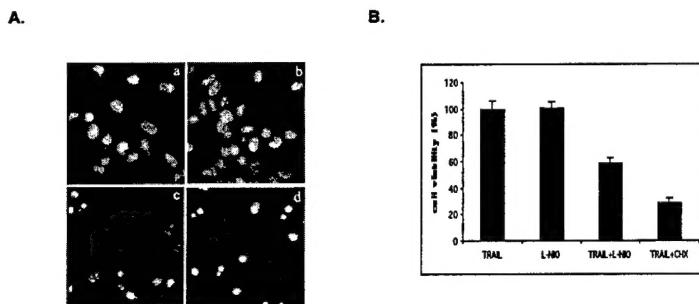


Figure 3. Inhibitor of eNOS sensitizes LNCaP cells to TRAIL. A. DNA staining of LNCaP cells treated with 500ng/ml TRAIL alone (a), 20mM L-NIO alone (b), TRAIL and L-NIO combination (c) or TRAIL and 10μg/ml cycloheximide combination (d). The cells were stained with Hoechst 33342 (5 μg/ml) and nuclear morphology was observed by fluorescent microscope. B. MTT assay of cell viability. Cell viability of LNCaP cells treated for 24 h with 500ng/ml TRAIL, 20mM L-NIO, 10μg/ml cycloheximide alone or in combinations. The viability was measured by MTT assay. Data represent means ± S.E.

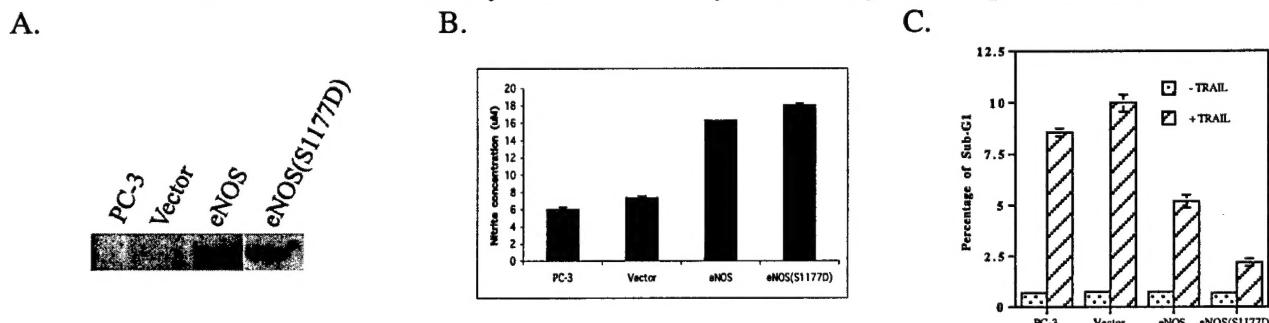


Figure 4. Overexpression of eNOS in PC-3 cells partially inhibit TRAIL-induced apoptosis. A. eNOS or eNOS (S1177D)-expressing clones. G418-resistant clones were expanded and cell lysates were probed with anti-eNOS antibody. B. eNOS activity in eNOS stable cell lines. Culture media from control PC-3 cells, empty vector clones, eNOS and eNOS (S1177D)-expressing clones were collected, and nitrites release was measured by using NO Assay kit (Molecular Probes Inc.). C. The percentage of cell death evaluated by flowcytometry. Cells (1×10^6) were treated with or without TRAIL (500ng/ml) for 24 h, stained with propidium iodide, and DNA content was analyzed by flowcytometry. The percentage of sub-G1 represented the percentage of cell death.

Task 2: To dissect the signaling pathway of TRAIL-induced apoptosis in PC cells (months 12-24):

- The role of a caspase cascade in TRAIL-induced apoptosis (months 12-15)
- The role of DISC formation in TRAIL-induced apoptosis (months 15-24)
- The role of mitochondria in TRAIL-induced apoptosis (months 15-24)

Results:

1) Both caspase cascade and mitochondrial pathway are important for TRAIL-induced apoptosis

To further dissect the signaling pathway of TRAIL-induced apoptosis in PC cells, we transiently

expressed various inhibitors in PC-3 cells and examined the TRAIL sensitivity. As shown in Figure 5, pan-caspase inhibitor zVAD-fmk, caspase-8 dominant negative mutant and FADD dominant negative mutant can effectively inhibit TRAIL-induced apoptosis of PC-3 cells, indicating that caspase cascade and DISC formation are important for initiation of TRAIL signaling. To evaluate the mitochondria, we established stable cell lines to overexpress Bcl-xL, a potent inhibitor of apoptosis. As shown in Figure 6, overexpression of Bcl-xL can inhibit TRAIL-induced apoptosis in the absence and presence of cycloheximide (only the presence of cycloheximide is shown here). This result suggests that both caspase cascade and mitochondrial pathway contribute to TRAIL-induced apoptosis.

Figure 5

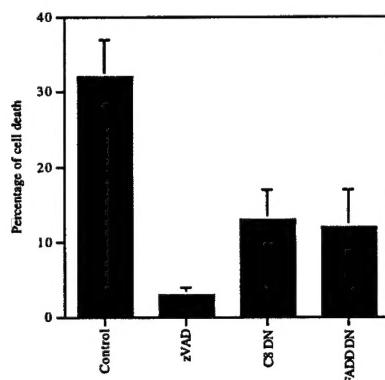


Figure 6

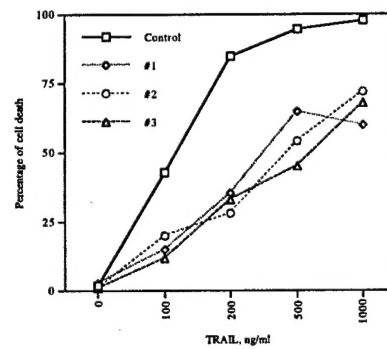


Figure 5: TRAIL-induced apoptosis of PC-3 cells is caspase-dependent. PC-3 cells were co-transfected with various constructs along with EGFP. After 24-hr transfection, cells were treated with TRAIL (500 ng/ml) for additional 24 hours. Percentage of cell death was scored by counting dead and alive green fluorescent cells.

Figure 6: Overexpression of Bcl-xL partially inhibits TRAIL-induced apoptosis of PC-3 cells. Three stable lines expressing Bcl-xL and control cell lines were treated with various amounts of TRAIL in the presence of cycloheximide (10 μ M/ml) for 24 hours. Percentage of cell death was evaluated by MTT assay.

2) Initial characterization of TRAIL receptors-interacting proteins:

It is generally believed that TRAIL signaling is similar to Fas signaling pathway, in which cross-linking of death receptors leads to the formation of Death-Inducing-Signaling-Complex (DISC) and activation of caspase-8. Active caspase-8 activates downstream caspase cascade and induces mitochondrial damage via BID cleavage, and results in apoptotic cell death. Nonetheless, TRAIL signaling is still poorly understood. To further understand TRAIL signaling in PC cells, we did a yeast 2-hybrid screening to identify proteins interacting with TRAIL receptors. We used the intracellular domains of TRAIL receptor DR4 and DR5 as baits and Clontech human prostate cDNA library. In order confirm the specificity, we used the DED domain of caspase-10 and the CARD domain of caspase-2 as negative controls. The initial identification of specific clones was summarized in Table 1. Although more work is needed to confirm the finding, there are a few interesting points that we can make by initial identification of these clones:

- Interestingly, not many clones can interact both DR4 and 5 except Filamins even though DR4 and 5 share high sequence homology. We currently do not have a good explanation for this observation.
- Multiple clones, namely UBC9 Saltzman et al, 1998), Daxx (Yang et al, 1997), Flash (Imai et al, 1999) and SODD (Jiang et al, 1999), have been demonstrated to interact with other death receptors such as Fas and TNFR1, indicating that DR5 may share a similar signaling pathway to Fas/TNFR1. This may also indirectly vindicates our screening result.
- Both UBC9 and PIASs are the components of sumoylation machinery (Jackson, 2001) Previous studies suggested the possible role of Sumo/Sentrin in regulation Fas-induced apoptosis (Okura et al, 1996). Further study will be needed to examine the role of sumoylation in TRAIL signaling.

Table1: Potential TRAIL receptors-interacting proteins identified by yeast 2-hybrid screening:

| DR4-interacting clones | | DR5-interacting clones | |
|--|------|---|------|
| Clone Names | Hits | Clone Names | Hits |
| DNAJB1 | 6 | UBC9 | 130 |
| DNAJB2 | 1 | Daxx | 1 |
| DNAJB4 | 2 | CGI99 | 14 |
| DNAJB6 | 3 | Filamin A | 3 |
| FKBP8 | 1 | APOE | 2 |
| BAT3 | 1 | Metallothionein | 2 |
| Calponin 3 | 1 | RAP80 (zinc finger protein) | 6 |
| Filamin A | 10 | G protein-coupled receptor kinase 6 | 1 |
| Filamin B | 2 | FLASH | 14 |
| CAP | 1 | PIAS1 | 2 |
| SHARP (SMART/HDAC1 associated protein) | 1 | PIASx | 3 |
| LAF4 (lymphoid nuclear protein) | 1 | SODD | 4 |
| Ribosomal protein S20 | 2 | Coatomer protein complex subunit 2 | 2 |
| Fatty acid binding protein 4 | 2 | Poly (rC)-binding protein 1 | 2 |
| Integrin beta 4 | 1 | Echinoderm microtubule associated protein 2 | 2 |
| C-terminal binding protein 1 | 2 | Lethal giant larvae homolog 2 | 1 |
| hnRNP H1 | 1 | Fibromodulin | 1 |
| Steroid receptor coactivator-1 | 1 | SECIS binding protein 2 | 1 |
| Similar to DKFZP434H132 protein | 2 | Clone B271E1 | 1 |
| KIAA1064 | 2 | Clone RP11-571I18 | 1 |
| KIAA0171 | 1 | Clone RP11-522I20 | 1 |
| CG8055 | 1 | Clone RP11-33I11 | 1 |
| FLJ21652 | 1 | Clone RP43-180A19 | 1 |
| Clone RP11-437B10 | 1 | Clone RPCI11-352M15 | 1 |
| Clone 4402152 | 1 | IgG heavy chain (G3m) | 2 |
| IgG HC | 9 | Annexin A6 | 1 |
| Novel | 1 | Novel | 1 |
| | | Novel | 1 |

KEY RESEARCH ACCOMPLISHMENTS:

- We found that most of prostate cancer cells were sensitive to TRAIL treatment while normal prostate epithelial cells were resistant.
- We found that high level of constitutively active pro-survival protein kinase Akt existed in TRAIL-resistant LNCaP cells. Inhibition of PI 3-kinase sensitized LNCaP cells to TRAIL.
- We found that the elevated eNOS activity by Akt phosphorylation may contribute to Akt-mediated TRAIL resistance in LNCaP cells.
- We did a yeast 2-hybrid screening to initially identify possible TRAIL receptors-interacting proteins

REPORTABLE OUTCOMES:

One manuscript was submitted for publication.

CONCLUSIONS:

Our in vitro data suggest that TRAIL is effective to induce most of prostate cancer cells to undergo apoptosis but not toxic to normal prostate epithelial cells. This result lay a solid foundation for further investigation of TRAIL's effect on prostate cancer cells *in vivo*. Elucidation of TRAIL signaling pathway and its regulation help us to understand the molecular mechanism of TRAIL resistance. Overcome of the anti-apoptotic mechanism, such as Akt's anti-apoptotic activity, in TRAIL-resistant cells by specific inhibitors will be the key for TRAIL-based therapy.

REFERENCES:

- Bookstein, R., MacGrogan, D., Hilsenbeck, S. G., Sharkey, F., Allred, D. C. (1993). p53 is mutated in a subset of advanced-stage prostate cancers. *Cancer Res.* 53, 3369-3373.
- Cardillo, M., Berchem, G., Tarkington, M. A., Krajewski, S., Krajewski, M., Reed, J. C., Tehan, T., Ortega, L., Lage, J., Gelmann, E. P. (1997). Resistance to apoptosis and up regulation of Bcl-2 in benign prostatic hyperplasia after androgen deprivation. *J. Urol.* 158, 212-216.
- Dimmeler S, Fleming I, Fisslthaler B, Hermann C, Busse R, Zeiher AM. (1999) Activation of nitric oxide synthase in endothelial cells by Akt-dependent phosphorylation. *Nature* 399, 601-5.
- Eastham, J. A., Stapleton, A. M. F., Gousse, A. E., Timme, T. L., Yang, G., Slawin, K. M., Wheeler, T. M., Scardino, P. T., Thompson, T. C. (1995). Association of p53 mutations with metastatic prostate cancer. *Clin. Cancer Res.* 1, 1111-1118.
- Fulton D, Gratton JP, McCabe TJ, Fontana J, Fujio Y, Walsh K, Franke TF, Papapetropoulos A, Sessa WC. (1999) Regulation of endothelium-derived nitric oxide production by the protein kinase Akt. *Nature* 399, 597-601.
- Imai Y, Kimura T, Murakami A, Yajima N, Sakamaki K, Yonehara S. (1999) The CED-4-homologous protein FLASH is involved in Fas-mediated activation of caspase-8 during apoptosis. *Nature* 398:777-85
- Jackson PK. (2001) A new RING for SUMO: wrestling transcriptional responses into nuclear bodies with PIAS family E3 SUMO ligases. *Genes Dev* 15:3053-8.
- Jiang Y, Woronicz JD, Liu W, Goeddel DV. (1999) Prevention of constitutive TNF receptor 1 signaling by silencer of death domains. *Science* 283:543-6.
- Nesterov A, Lu X, Johnson M, Miller GJ, Ivashchenko Y, Kraft AS. Elevated AKT activity protects the prostate cancer cell line LNCaP from TRAIL-induced apoptosis. *J Biol Chem* 2001; 276: 10767-74.
- Okura T, Gong L, Kamitani T, Wada T, Okura I, Wei CF, Chang HM, Yeh ET. (1996) Protection against Fas/APO-1- and tumor necrosis factor-mediated cell death by a novel protein, sentrin. *J Immunol* 157:4277-81.
- Pitti, R. M., Marsters, S. A., Ruppert, S., Donahue, C. J., Moore, A., Ashkenazi, A. (1996). Induction of apoptosis by Apo-2 ligand, a new member of the tumor necrosis factor cytokine family. *J. Biol. Chem.* 271, 12687-12690.
- Rees DD, Palmer RM, Schulz R, Hodson HF, Moncada S. Characterization of three inhibitors of endothelial nitric oxide synthase in vitro and in vivo. *Br J Pharmacol* 1990; 101: 746-52.

Saltzman A, Searfoss G, Marcireau C, Stone M, Ressner R, Munro R, Franks C, D'Alonzo J, Tocque B, Jaye M, Ivashchenko Y. (1998) hUBC9 associates with MEKK1 and type I TNF-alpha receptor and stimulates NFkappaB activity. FEBS Lett 425: 431-5.

Thakkar H, Chen X, Tyan F, Gim S, Robinson H, Lee C, Pandey SK, Nwokorie C, Onwudiwe N, Srivastava RK. (2001) Pro-survival function of Akt/protein kinase B in prostate cancer cells: relationship with trail resistance. J Biol Chem 276, 38361-9.

Wiley, S. R., Schooley, K., Smolak, K., Din, W. S., Huang, C. P., Nicholl, J. K., Sutherland, G. R., Smith, T. D., Rauch, C., Smith, C. A., et al (1995). Identification and characterization of a new member of the TNF family that induces apoptosis. Immunity 3, 673-682.

Yang X, Khosravi-Far R, Chang HY, Baltimore D. (1997) Daxx, a novel Fas-binding protein that activates JNK and apoptosis. Cell 89:1067-76.

eNOS Protects Prostate Cancer Cells from TRAIL-induced apoptosis

Xin Tong¹, Honglin Li^{1,2}

¹Children's Memorial Institute for Education and Research, The Robert H. Lurie
Comprehensive Cancer Center, The Feinberg School of Medicine, Northwestern
University, Chicago, Illinois 60614

²To whom responses should be addressed:

Honglin Li, Children's Memorial Institute for Education and Research, 2300 Children's
Plaza, Box 209, Chicago, IL 60614. Phone: (773) 975-8518, Fax: (773) 868-8066; E-
mail: h-li2@northwestern.edu

Running title: eNOS inhibits TRAIL-induced apoptosis

ABSTRACT

Background: The TNF-related apoptosis-inducing ligand, TRAIL (also called Apo2L), has recently been emerging as a non-toxic anti-cancer agent because it is capable of inducing apoptosis in many of tumor cell lines but not in most of normal cells tested. Preclinical experiments in rodents and nonhuman primates have shown that administration of TRAIL suppresses tumor growth without apparent systematic cytotoxicity. Therefore, TRAIL represents a potential tumor-specific anti-cancer agent. To exploit the potential use of TRAIL as an anti-prostate cancer therapeutic agent, we examined the cytotoxic effect of TRAIL on normal human prostate epithelial cells (PrEC) and cancer cells (namely, PC-3, DU 145, TSU-Pr1, ALVA-31 and LNCaP).

Methods: Normal prostate epithelial cell and various prostate cancer cells were used to test the sensitivity of these cells to TRAIL treatment. Cells were incubated with soluble TRAIL, and the percentages of cell death were evaluated by MTT assay. To further investigate the signaling pathway of TRAIL-induced apoptosis, we used immunoblotting to examine the expression levels of various components possibly involved in TRAIL signaling. Furthermore, we established a stable cell line of eNOS to evaluate the effect of eNOS on TRAIL-mediated apoptosis.

Results: We examined the effect of TRAIL on human prostate normal and cancer cell lines, and found that the prostate cancer cell lines PC-3, ALVA-31, DU 145 and TSU-Pr1 were sensitive to TRAIL-induced apoptosis, while normal PrEC cells and cancer cell line LNCaP were resistant. The intracellular mechanism of LNCaP cells' resistance to TRAIL was further investigated. No correlation was found between the sensitivity of

cells to TRAIL and the expression of TRAIL receptors DR4 and DR5, and pro-apoptotic proteins Bax and Bak. However, LNCaP cells displayed a high Akt activity.

Furthermore, we found that endothelial nitric oxide synthase (eNOS), one of the Akt substrates, was highly expressed in LNCaP but not in other cells. Inhibition of eNOS activity by NOS inhibitor sensitized LNCaP cells to TRAIL. Moreover, PC-3 cell clones stably expressing eNOS were resistant to TRAIL-induced apoptosis.

Conclusion: Taken together, these results indicate that eNOS is one of Akt substrates that can regulate the sensitivity of prostate cancer cells to TRAIL, and down-regulation of eNOS activity may sensitize cancer cells to TRAIL-based therapy.

Key words: prostate cancer cells, apoptosis, TRAIL, Akt, eNOS

INTRODUCTION

Prostate cancer is the most commonly diagnosed cancer and one leading cause of male cancer death[1]. Unfortunately, there are limited treatment options available for this disease, in addition to androgen ablation[2]. However, metastatic cancers frequently develop from a small number of androgen-independent cancer cells after surgery. Those cells are highly resistant to traditional chemotherapies so that the disease is incurable in later stages. Therefore, more effective agents should be developed to combat metastatic prostate cancers.

TRAIL (tumor necrosis factor-related apoptosis-inducing ligand) is a potent apoptosis-inducing cytokine that together with tumor necrosis factor- α (TNF- α), Fas ligand and Apo3L, constitutes a family of ligands that induce apoptosis through binding their corresponding death receptors[3, 4]. Unlike TNF- α and Fas ligand, whose use for anti-cancer therapy has been hampered by their severe toxicity[5, 6], TRAIL appears to specifically kill a wide variety of cancer cells in culture and xenografted tumors while leaving most of normal cells and tissues unharmed[7]. Preclinical experiments in rodents and nonhuman primates have shown that administration of TRAIL suppresses tumor growth without apparent systematic cytotoxicity[7, 8]. Therefore, TRAIL represents a potential tumor-specific anti-cancer agent. Recent studies indicate that the signaling pathway of TRAIL-induced apoptosis is largely similar to the Fas signaling pathway[9]. Five receptors that interact with TRAIL have been identified, including the apoptosis-inducing receptors DR4/TRAIL-R1 and DR5/TRAIL-R2/Killer/TRICK2[10-12], the decoy receptors DcR1/TRAIL-R3/TRID (without an intracellular domain) and DcR2/TRAIL-R4 (with a truncated death domain)[10, 12-14], and osteoprotegerin[15].

Through recruiting adapter protein FADD and caspase-8, engagement of TRAIL to its receptors (DR4 and DR5) triggers the formation of so-called death-inducing signaling complex (DISC), which results in activation of caspase-8 and apoptosis of target cells[9]. Nonetheless, the molecular mechanism underlying the tumor cell-specific cytotoxicity of TRAIL remains largely unclear.

Akt is a serine/threonine kinase that has been identified as a key component of multiple pro-survival signaling pathways[16]. It has been shown that Akt phosphorylates and inactivates multiple pro-apoptotic factors such as BAD[17], caspase-9[18] and the Forkhead transcriptional factors[19, 20]. Moreover, Akt exerts its pro-survival functions via stimulating glucose metabolism[21]. Previous studies have shown that there is an elevated Akt activity in TRAIL-resistant prostate cancer cells, and down-regulation of constitutively active Akt by phosphatidylinositol 3-kinase (PI3K) inhibitors reverses cellular resistance to TRAIL[22, 23]. Furthermore, overexpression of constitutively active Akt in cells with low Akt activity inhibits TRAIL-induced apoptosis[23]. Nonetheless, not all prostate cancer cells with low Akt activity can gain the ability to resist TRAIL-induced apoptosis when they express constitutively active Akt[22]. This observation indicates that the protective effect of Akt may be cell type-specific, and other factors may contribute to Akt-mediated resistance to TRAIL-induced apoptosis.

In the present study, we examined the cytotoxic effect of TRAIL on human prostate normal epithelial cells (PrEC) and cancer cells (namely, PC-3, DU 145, TSU-Pr1, ALVA-31 and LNCaP). We demonstrated that normal PrEC and cancer LNCaP cells were resistant to TRAIL treatment, while other cancer cells were sensitive to TRAIL. The mechanisms underlying LNCaP cells' resistance was further investigated,

and we found that eNOS, a substrate of Akt, was highly expressed in LNCaP cells. Inhibition of eNOS sensitized LNCaP cells to TRAIL, while over-expression of eNOS enabled PC-3 cells partially resistant to TRAIL, suggesting that eNOS activity may contribute to regulation of TRAIL signaling pathway.

MATERIALS AND METHODS

Reagents

Antibodies were purchased from the following sources: anti-PTEN, anti-Bax (Santa Cruz Biotechnology Inc, Santa Cruz, CA); anti-phospho-Akt, anti-Akt (New England Biolabs, Beverly, MA); anti-DR5 (StressGen Biotechnologies Corp, Victoria, Canada); anti-DR4, anti-Bak (Upstate Biotechnology, Lake Placid, NY); anti-eNOS, anti-nNOS, anti-iNOS (Transduction Laboratories, Lexington, KY); anti-Tubulin (Sigma). Anti-caspase-8 and anti-BID antibodies were a gift from Dr. Junying Yuan. L-N⁵-(1-iminovethyl)-ornithine (L-NIO) was obtained from Calbiochem (San Diego, CA), 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) and Hoechst 33342 were from Sigma.

Cell Cultures

Human prostate normal PrEC cells were purchased from Bio-Whittaker (Walkersville, MA), and were grown in PrEGM medium (Bio-Whittaker). Human prostate cancer PC-3, DU 145, TSU and LNCaP cells were kindly provided by Dr. Z. Wang, and ALVA-31 was provided by Dr. S. M. Loop. These cells were grown in RPMI 1640 medium with 10% fetal bovine serum. All cells were maintained on tissue culture dishes at 37 °C with 5% CO₂.

Expression of Recombinant TRAIL

The expression construct was pET-15b-His-TRAIL, which encodes for soluble human TRAIL (residues 95-281). *E. coli* BL21(DE3) transformed with this construct were grown in LB medium to exponential phase, and induced with 0.4 mM isopropyl-1-thio-β-D-galactopyranoside for 2 h. Cells were pelleted, resuspended in lysis buffer (5

mM imidazole, 0.5 M NaCl, 20 mM Tris-HCl, pH7.9), and sonicated. The supernatant after centrifugation at 12000× g for 30 min was used for purification of His-tagged TRAIL following the manufacturer's instructions (Novagen).

MTT Assay

1×10^4 cells (50 μ l) were subcultured in RPMI 1640 (phenol red-free) supplemented with 10% fetal bovine serum in a 96-well plate, and treated with or without TRAIL for 24 h at 37 °C and 5% CO₂. For MTT assays, 5 μ l of MTT agent (5 mg/ml in phenol red-free RPMI 1640) was added and further incubated for 2 h. Equal volumes of 0.05 M HCl in isopropanol were then added, and cells were disrupted by pipetting up and down. The spectrophotometric absorbance of the sample was measured using an automated 96-well plate reader. The wavelength to measure absorbance was 570 nm, and the reference wavelength was 650 nm.

Western Blotting

Cells were harvested and lysed in sample loading buffer, and cell lysates were subjected to SDS-PAGE followed by transferring to Immobilon-P membranes (Millipore, Bedford, MA). The membranes were blocked in TBST buffer (20 mM Tris-HCl, pH7.5, 150mM NaCl, 0.2% Tween-20) containing 5% non-fat dried milk overnight at 4 °C. Membranes were then blotted with various primary antibodies for 2 h at room temperature. After washing three times in TBST, membranes were subsequently incubated with horseradish peroxidase-conjugated secondary antibodies for 30 min at room temperature. Proteins were detected by ECL (PerkinElmer Life sciences, Inc., Boston, MA) according to the manufacturer's instructions.

Transfection and Selection of Stable Clone

Plasmids encoding the human eNOS and mutant eNOS (S1179D), a kind gift from Dr. Stefanie Dimmeler (University of Frankfurt, Germany), were transfected into PC-3 cells by LIPOFECTAMINE Reagent (Invitrogen, Carlsbad, CA). The control was the vector pcDNA 3.1/Myc-His. At 48 h after transfection, the cells were detached with trypsin and re-plated in the medium with G418 (500 μ g/ml). After 2-week selection, G418-resistant colonies were expanded in 24-well plate and maintained in medium supplement with G418. The stable cell lines expressing eNOS were screened with anti-Myc antibody.

Nitrite Detection

Quantitative analysis of nitrite was used as an index of NO production. 1×10^6 cells were plated onto a 6-well plate, culture supernatants were collected after 24 h culture and assayed for nitrite using Nitric Oxide Assay Kit (Calbiochem), following the manufacturer's instructions. Briefly, samples were aliquoted into 96-well plate. Nitrates were reduced to nitrites by nitrate reductase in the presence of NADH. Total nitrates in the samples and in the standards (0.5-25 μ M solutions of sodium nitrite) were detected colorimetrically with Griess regents I and II and measured at 540 nm. Culture medium (in the absence of cells) served as sample blanks.

Flow Cytometric Analysis

Cells were trypsinized, washed in PBS and fixed with ice-cold 70% ethanol. Cells were then washed in PBS again and resuspended in PBS containing RNaseA and propidium iodide. A total of 10000 labeled nuclei were analyzed in a FACScan Flow

Cytometer (Becton Dickinson, Mansfield, MA). The numbers of cells with sub-G₁ DNA content were determined as indicators of apoptotic population.

RESULTS

Effect of TRAIL on human prostate normal and cancer cells

Recombinant human TRAIL (residues 95-281) was produced in *Escherichia coli* as a fusion protein containing an N-terminal His-tag, and purified by using standard nickel affinity chromatography. Cytotoxic effects of TRAIL on human prostate normal epithelial cells (PrEC) and cancer cell lines (namely, PC-3, TSU-Pr1, DU 145, ALVA-31 and LNCaP) were evaluated by MTT assay. As shown in Figure 1A, PC-3 and ALVA-31 cells were sensitive to TRAIL, and DU 145 and TSU-Pr1 revealed moderate sensitivity, while LNCaP and normal PrEC cells were fully resistant to TRAIL treatment.

Expression of TRAIL receptors and pro-apoptotic proteins in prostate cells

To investigate the intracellular mechanisms underlying differential sensitivity of prostate cancer cells to TRAIL, we firstly examined the expression level of TRAIL receptors (DR4 and DR5). As shown in Figure 1B, no correlation was found between the TRAIL sensitivity and the expression of TRAIL receptors DR4 and DR5 among the five prostate cancer cell lines that we tested. On the contrary, higher DR4 expression was found in LNCaP cells. PrEC cells expressed low level of DR5 but not DR4 (Fig. 1B). Recent study has shown that hepatocytes of Bax/Bak double knockout mice resist death receptor-induced apoptosis in vivo [24]. Additionally, LeBlanc *et al.* reported that Bax-deficient human colon carcinoma cells are resistant to TRAIL, whereas Bax-expressing sister clones are sensitive [25]. Deng *et al.* also confirmed that Bax is required for TRAIL-induced apoptosis of certain cancer cell lines[26]. We further examined the expression of these pro-apoptotic proteins in prostate cancer cells. As shown in Figure

1B, all cells we tested expressed comparable amounts of Bax and Bak, indicating that Bax/Bak are not the determinant of TRAIL sensitivity of these prostate cancer cells. Since an excessive amount of soluble TRAIL was used in this in vitro assay, TRAIL decoy receptors should not play an important role in TRAIL sensitivity under this assay condition.

LNCaP Cells expresses high levels of active Akt and eNOS protein

Akt is a serine/threonine protein kinase that has been implicated in mediating a variety of biological responses including inhibiting apoptosis and stimulating cellular growth. Akt is activated via PI3K signaling pathway[16], whereas PTEN, a tumor suppressor protein, negatively regulates the PI3K signaling pathway which in turn down-regulates Akt's activity[27, 28]. Previous studies have demonstrated that LNCaP cells have a high level of constitutive active Akt due to the deletion and mutation at PTEN alleles[23]. Inhibition of PI3K activity using wortmannin and LY-294002 suppresses constitutive Akt activity and sensitizes LNCaP cells to TRAIL. Conversely, overexpression of constitutively active Akt attenuates TRAIL-induced apoptosis[22, 23]. By repeating these experiments, we found that there was no PTEN expression in LNCaP cells, in which the highest Akt activity was observed, although total Akt protein levels among these prostate cancer cells were similar (Fig. 2). This observation further confirmed the correlation between Akt activity and TRAIL resistance. However, DU 145, a TRAIL-sensitive prostate cancer cell line with low Akt activity, were still sensitive to TRAIL even in the presence of constitutively active Akt (35). This result suggests that there may be some other molecules rather than Akt alone contribute to TRAIL-resistance.

So far, multiple Akt substrates, including BAD, caspase-9 and Forkhead transcription factors, have been found to be involved in regulation of apoptotic signaling pathway[17-20]. Another interesting substrate is eNOS, whose activity is enhanced when modified by Akt[29, 30]. To explore whether eNOS may be involved in TRAIL-resistance, we examined the expression of three isoforms of NOS among the five prostate cancer cells. As shown in Fig. 2, only LNCaP cells expressed eNOS, whereas all of them expressed nNOS, but do not express iNOS.

NOS inhibitor sensitized LNCaP cells to TRAIL-induced apoptosis

To further examine whether the high-level expression of eNOS in LNCaP cells contributes to TRAIL resistance, we used eNOS inhibitor to test if inhibition of eNOS can sensitize LNCaP cells to TRAIL. L-NIO is a potent inhibitor of eNOS compared to other arginine analogs[31]. LNCaP cells were pre-treated with L-NIO for 2 h before exposure to TRAIL (500ng/ml), and cell death was evaluated by nuclear morphology and measured by MTT assay after 24 h treatment. As shown in Fig. 3A and 3B, TRAIL or L-NIO alone did not induce any cell death (2% cell death), but pretreatment with L-NIO or protein synthesis inhibitor (cycloheximide) sensitized LNCaP cells to TRAIL-induced apoptosis (38% and 76% cell death, respectively).

eNOS expression partially inhibits TRAIL-induced apoptosis of PC-3 cells

The potent effect of eNOS inhibitor L-NIO on sensitivity of LNCaP cells to TRAIL treatment suggests that eNOS may be involved in the inhibition of TRAIL signaling pathway in LNCaP cells. To further test this possibility, we used PC-3 cells as

a model system to test the effect of eNOS on TRAIL-induced apoptosis, because PC-3 cells were most sensitive to TRAIL among the five prostate cancer cells we tested (Fig. 1A) and have no expression of eNOS (Fig. 2). Wild type eNOS and mutant eNOS (S1177D) (Mutation of serine 1177 into aspartic acid that substitutes for the negative charge afforded by the addition of phosphate and mimics the activation state induced by Akt) were introduced into PC-3 cells by gene transfection, and stable clones were selected. We randomly selected 30 G418-resistant clones, among which 6 clones expressed wild-type eNOS and 4 clones expressed eNOS (S1177D), respectively (Fig. 4A). The clones with high-level expression of eNOS were tested for their TRAIL sensitivity. Empty vector was also introduced into PC-3 cells and G418-resistant clones were selected as a control. We also evaluated the enzymatic activities of eNOS or eNOS (S1177D) in these stable clones by measuring NO level. In aqueous solution, NO is rapidly oxidized to two stable breakdown products, nitrate and nitrite, which can be detected by colorimetric means. In the present assay, nitrates were further reduced to nitrites by nitrate reductase in the presence of NADH, and total nitrate concentration was determined. As shown in Fig. 4B, in comparison to parental PC-3 cells and empty vector clones that produced 6 μ M and 6.6 μ M of NO, respectively, eNOS clone #8 produced high level of NO (16.2 μ M), while eNOS (S1177D) clone #14 produced the highest level of NO (17.2 μ M).

We further examined whether these eNOS stable cell lines are resistant to TRAIL-induced apoptosis. Cells were treated with TRAIL (500ng/ml) for up to 24 h, and the DNA content was analyzed by flow cytometry. The sub-G₁ DNA peak, characteristic of apoptotic cell death, was clearly detectable in PC-3 cells (8.6% \pm 0.3%) or empty vector

clones ($10.0\% \pm 0.7\%$) treated with TRAIL with respect to untreated controls, while eNOS-expressing cells have much lower sub-G₁ peak ($5.2\% \pm 0.3\%$), and the lowest sub-G₁ peak was observed in eNOS (S1177D)-expressing cells ($2.4\% \pm 0.1\%$) (Fig. 4C). These results demonstrated that overexpression of eNOS in TRAIL sensitive PC3 cells can inhibit TRAIL-induced apoptosis, further indicating the role of eNOS in regulation of TRAIL signaling.

eNOS expression does not block Caspase-8 activation and BID cleavage

In LNCaP cells, activation of caspase-8 is induced by TRAIL alone, but cleavage of caspase-8 substrate Bid is not detected unless TRAIL is administered in combination with PI3K inhibitor[22, 23]. This finding indicates that TRAIL-induced apoptotic signaling in LNCaP cells is blocked at the level of Bid cleavage. In TRAIL-sensitive PC-3 cells, we found both caspase-8 activation and Bid cleavage could be detected by TRAIL treatment alone (data not shown). Since eNOS expression can protect PC-3 cells from TRAIL-induced apoptosis, we further examined whether overexpression of eNOS can also inhibit caspase-8 activation and Bid cleavage. As shown in Fig. 5, caspase-8 activation and Bid cleavage were still detected in eNOS (S117D)-expressing PC-3 cells. This result suggests that eNOS may inhibit events downstream of mitochondrial damage rather than cleavage of BID.

DISCUSSION

In this report, we examined the cytotoxic effect of TRAIL on human prostate normal and cancer cells. Cell viability assays demonstrated that prostate cancer PC-3 and

ALVA-31 cells were sensitive to TRAIL treatment, and DU 145 and TSU-Pr1 cells revealed moderate sensitivity, whereas LNCaP and normal PrEC cells were resistant to TRAIL. Regulation of TRAIL signaling can occur at multiple points. First, at the ligand-receptor level, the initiation of TRAIL-induced apoptosis may be inhibited by down-expression of TRAIL receptors DR4 or DR5 or over-expression of decoy receptors DcR1 or DcR2[32]. Although we found that normal PrEC cells didn't express DR4, and had low level of DR5 expression, there were no correlation between the sensitivity of cells to TRAIL and the expression of DR4 and DR5 among the five prostate cancer cell lines that we tested. In contrast, higher DR4 expression was found in TRAIL-resistant LNCaP cells. Previous report also demonstrated that no difference in expression of DcR1 and DcR2 exists among these cells[22]. Second, at the level of DISC, the formation of DISC could be inhibited by cFLIP protein that is capable of blocking the activation of caspase-8[33]. Previous studies and our data (data not shown) indicated that cFLIP does not render TRAIL sensitivity in these prostate cancer cells[22]. Third, in so-called type II cells that the mitochondrial pathway is required to amplify the apoptotic signal[34]. Recent reports demonstrated that pro-apoptotic protein Bax is required for TRAIL-induced apoptosis[25, 26]. Again, no difference in the expression level of Bax among prostate cancer cells was observed. Finally, IAP family proteins may inhibit downstream caspases, which also determine the sensitivity of TRAIL treatment[35]. Still we couldn't find the difference of the expression of XIAP among these prostate cancer cells (data not shown).

So what determine the resistance of LNCaP cells to TRAIL treatment? It has been reported that a high level of constitutively active Akt activity in LNCaP cells may

contribute to TRAIL resistance[22, 23]. Along this line, our present study further identified eNOS, a substrate of Akt, which can regulate the sensitivity of prostate cancer cells to TRAIL-mediated apoptosis. We found that only TRAIL-resistant LNCaP cells expressed high level of eNOS, while no eNOS expression was detected in TRAIL-sensitive cells. NOS inhibitor L-NIO, a potent inhibitor of eNOS, sensitized LNCaP cells to TRAIL. Finally, the PC-3 cell clones stably expressing eNOS inhibited apoptosis induced by TRAIL, while the parent PC-3 cells were sensitive to TRAIL. Taken together, these findings demonstrated that eNOS plays an important regulatory role in TRAIL signaling pathway in prostate cancer cells. Our study further indicates that manipulation of eNOS activity may provide additional tools to improve efficacy of TRAIL-based anti-cancer therapy.

Previous studies have demonstrated that NO can exert an anti-apoptotic function in response to pro-apoptotic stimuli such as TNF α , Fas, removal of growth factors or UV irradiation[36]. The anti-apoptotic effect of NO can be achieved through regulating expression of apoptosis-protective genes as heat shock protein 70, Bcl-2, and inhibiting Bcl-2 cleavage, cytochrome C release, and ceramide formation as well as directly inhibiting caspase-3, caspase-8 by S-nitrosylation[37-40]. In the present study, caspase-8 activation and Bid cleavage could still be detected in PC3 cells overexpressing eNOS when treated with TRAIL, suggesting that S-nitrosylation of caspase-8 may not be involved, and the mechanisms by which eNOS protects cells from TRAIL-induced apoptosis need be further investigated.

Acknowledgements:

This work has been supported by grant DAMA17-01-1-0042 from Department of Defense (to H. L.) and the seed grant of CMIER (to H. L.). We thank Dr. Stefanie Dimmeler for eNOS constructs, Dr. Stephen Loop for ALVA-31 cell line and Dr. Zhou Wang for various prostate cell lines and his expertise in prostate cancer research.

Abbreviations:

TRAIL, tumor necrosis factor-related apoptosis-inducing ligand;

TNF- α , tumor necrosis factor- α ;

DISC, death-inducing signaling complex;

PI3K, phosphatidylinositol 3-kinase;

PIP₃, phosphatidylinositol 3,4,5-triphosphate;

NO, nitric oxide;

NOS, NO synthase;

eNOS, endothelial NOS;

nNOS, neuronal NOS; iNOS, inducible NOS;

HSP, heat shock protein;

L-NIO, L-N⁵-(1-methyl)-ornithine, Dihydrochloride;

MTT, 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide.

Figures Legends

Figure 1. Effect of TRAIL on cell viability of human prostate normal and cancer cells. A. The effect of TRAIL on cell viability. Cells were treated with TRAIL (500ng/ml) for 24 h, and viability was measured by MTT assay. Data represent mean \pm S.E. B. Expression of TRAIL receptors and pro-apoptotic proteins in prostate cancer and normal cells. Cell lysates prepared from prostate normal and cancer cells were probed by immunoblotting with anti-DR4, anti-DR5, anti-Bax, and anti-Bak antibodies.

Figure 2. LNCaP cells express high level of eNOS. Cell lysates from five prostate cancer cell lines were probed by immunoblotting with anti-PTEN, anti-Akt, anti-phospho-Akt, anti-nNOS, anti-iNOS and anti-eNOS.

Figure 3. Inhibitor of eNOS sensitizes LNCaP cells to TRAIL. A. DNA staining of LNCaP cells treated with 500ng/ml TRAIL alone (a), 20mM L-NIO alone (b), TRAIL and L-NIO combination (c) or TRAIL and 10 μ g/ml cycloheximide combination (d). The cells were stained with Hoechst 33342 (5 μ g/ml) and nuclear morphology was observed by fluorescent microscope. B. MTT assay of cell viability. Cell viability of LNCaP cells treated for 24 h with 500ng/ml TRAIL, 20mM L-NIO, 10 μ g/ml cycloheximide alone or in combinations. The viability was measured by MTT assay. Data represent means \pm S.E.

Figure 4. Overexpression of eNOS in PC-3 cells partially inhibit TRAIL-induced apoptosis. A. eNOS or eNOS (S1177D)-expressing clones. G418-resistant clones were

expanded and cell lysates were probed with anti-eNOS antibody. B. eNOS activity in eNOS stable cell lines. Culture media from control PC-3 cells, empty vector clones, eNOS and eNOS (S1177D)-expressing clones were collected, and nitrites release was measured by using NO Assay kit (Molecular Probes Inc.). C. The percentage of cell death evaluated by flowcytometry. Cells (1×10^6) were treated with or without TRAIL (500ng/ml) for 24 h, stained with propidium iodide, and DNA content was analyzed by flowcytometry. The percentage of sub-G1 represented the percentage of cell death.

Figure 5. Overexpression of eNOS in PC-3 cells does not block caspase-8 activation and Bid cleavage. eNOS (S1177D)-expressing PC-3 cells were treated with TRAIL (200ng/ml) from 4 h to 24 h, and cell lysates were probed with anti-caspase-8 and anti-Bid antibodies.

REFERENCES

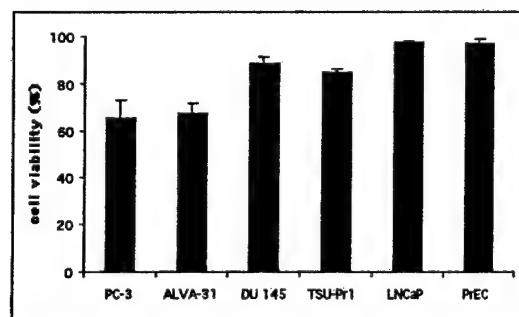
1. Hsing AW, Tsao L, Devesa SS. International trends and patterns of prostate cancer incidence and mortality. *Int J Cancer* 2000; 85: 60-7.
2. Crawford ED, Eisenberger MA, McLeod DG, Spaulding JT, Benson R, Dorr FA, Blumenstein BA, Davis MA, Goodman PJ. A controlled trial of leuprolide with and without flutamide in prostatic carcinoma. *N Engl J Med* 1989; 321: 419-24.
3. Wiley SR, Schooley K, Smolak PJ, Din WS, Huang CP, Nicholl JK, Sutherland GR, Smith TD, Rauch C, Smith CA, et al. Identification and characterization of a new member of the TNF family that induces apoptosis. *Immunity* 1995; 3: 673-82.
4. Pitti RM, Marsters SA, Ruppert S, Donahue CJ, Moore A, Ashkenazi A. Induction of apoptosis by Apo-2 ligand, a new member of the tumor necrosis factor cytokine family. *J Biol Chem* 1996; 271: 12687-90.
5. Vassalli P. The pathophysiology of tumor necrosis factors. *Annu Rev Immunol* 1992; 10: 411-52.
6. Nagata S. Apoptosis by death factor. *Cell* 1997; 88: 355-65.
7. Walczak H, Miller RE, Ariaill K, Gliniak B, Griffith TS, Kubin M, Chin W, Jones J, Woodward A, Le T, Smith C, Smolak P, Goodwin RG, Rauch CT, Schuh JC, Lynch DH. Tumoricidal activity of tumor necrosis factor-related apoptosis-inducing ligand in vivo. *Nat Med* 1999; 5: 157-63.
8. Ashkenazi A, Pai RC, Fong S, Leung S, Lawrence DA, Marsters SA, Blackie C, Chang L, McMurtrey AE, Hebert A, DeForge L, Koumenis IL, Lewis D, Harris L, Bussiere J, Koeppen H, Shahrokh Z, Schwall RH. Safety and antitumor activity of recombinant soluble Apo2 ligand. *J Clin Invest* 1999; 104: 155-62.
9. Peter ME. The TRAIL DISCUSSION: It is FADD and caspase-8! *Cell Death Differ* 2000; 7: 759-60.
10. Pan G, Ni J, Wei YF, Yu G, Gentz R, Dixit VM. An antagonist decoy receptor and a death domain-containing receptor for TRAIL. *Science* 1997; 277: 815-8.
11. Pan G, O'Rourke K, Chinnaiyan AM, Gentz R, Ebner R, Ni J, Dixit VM. The receptor for the cytotoxic ligand TRAIL. *Science* 1997; 276: 111-3.

12. Sheridan JP, Marsters SA, Pitti RM, Gurney A, Skubatch M, Baldwin D, Ramakrishnan L, Gray CL, Baker K, Wood WI, Goddard AD, Godowski P, Ashkenazi A. Control of TRAIL-induced apoptosis by a family of signaling and decoy receptors. *Science* 1997; 277: 818-21.
13. Marsters SA, Sheridan JP, Pitti RM, Huang A, Skubatch M, Baldwin D, Yuan J, Gurney A, Goddard AD, Godowski P, Ashkenazi A. A novel receptor for Apo2L/TRAIL contains a truncated death domain. *Curr Biol* 1997; 7: 1003-6.
14. Pan G, Ni J, Yu G, Wei YF, Dixit VM. TRUNDD, a new member of the TRAIL receptor family that antagonizes TRAIL signalling. *FEBS Lett* 1998; 424: 41-5.
15. Emery JG, McDonnell P, Burke MB, Deen KC, Lyn S, Silverman C, Dul E, Appelbaum ER, Eichman C, DiPrinzio R, Dodds RA, James IE, Rosenberg M, Lee JC, Young PR. Osteoprotegerin is a receptor for the cytotoxic ligand TRAIL. *J Biol Chem* 1998; 273: 14363-7.
16. Downward J. Mechanisms and consequences of activation of protein kinase B/Akt. *Curr Opin Cell Biol* 1998; 10: 262-7.
17. Datta SR, Dudek H, Tao X, Masters S, Fu H, Gotoh Y, Greenberg ME. Akt phosphorylation of BAD couples survival signals to the cell-intrinsic death machinery. *Cell* 1997; 91: 231-41.
18. Cardone MH, Roy N, Stennicke HR, Salvesen GS, Franke TF, Stanbridge E, Frisch S, Reed JC. Regulation of cell death protease caspase-9 by phosphorylation. *Science* 1998; 282: 1318-21.
19. Brunet A, Bonni A, Zigmond MJ, Lin MZ, Juo P, Hu LS, Anderson MJ, Arden KC, Blenis J, Greenberg ME. Akt promotes cell survival by phosphorylating and inhibiting a Forkhead transcription factor. *Cell* 1999; 96: 857-68.
20. Kops GJ, de Ruiter ND, De Vries-Smits AM, Powell DR, Bos JL, Burgering BM. Direct control of the Forkhead transcription factor AFX by protein kinase B. *Nature* 1999; 398: 630-4.
21. Gottlob K, Majewski N, Kennedy S, Kandel E, Robey RB, Hay N. Inhibition of early apoptotic events by Akt/PKB is dependent on the first committed step of glycolysis and mitochondrial hexokinase. *Genes Dev* 2001; 15: 1406-18.

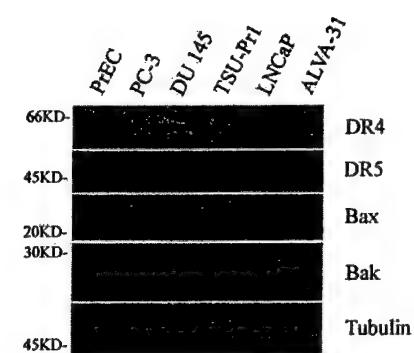
22. Nesterov A, Lu X, Johnson M, Miller GJ, Ivashchenko Y, Kraft AS. Elevated AKT activity protects the prostate cancer cell line LNCaP from TRAIL-induced apoptosis. *J Biol Chem* 2001; 276: 10767-74.
23. Thakkar H, Chen X, Tyan F, Gim S, Robinson H, Lee C, Pandey SK, Nwokorie C, Onwudiwe N, Srivastava RK. Pro-survival function of Akt/protein kinase B in prostate cancer cells: relationship with trail resistance. *J Biol Chem* 2001; 276: 38361-9.
24. Wei MC, Zong WX, Cheng EH, Lindsten T, Panoutsakopoulou V, Ross AJ, Roth KA, MacGregor GR, Thompson CB, Korsmeyer SJ. Proapoptotic BAX and BAK: a requisite gateway to mitochondrial dysfunction and death. *Science* 2001; 292: 727-30.
25. LeBlanc H, Lawrence D, Varfolomeev E, Totpal K, Morlan J, Schow P, Fong S, Schwall R, Sinicropi D, Ashkenazi A. Tumor-cell resistance to death receptor--induced apoptosis through mutational inactivation of the proapoptotic Bcl-2 homolog Bax. *Nat Med* 2002; 8: 274-81.
26. Deng Y, Lin Y, Wu X. TRAIL-induced apoptosis requires Bax-dependent mitochondrial release of Smac/DIABLO. *Genes Dev* 2002; 16: 33-45.
27. Myers MP, Pass I, Batty IH, Van der Kaay J, Stolarov JP, Hemmings BA, Wigler MH, Downes CP, Tonks NK. The lipid phosphatase activity of PTEN is critical for its tumor suppressor function. *Proc Natl Acad Sci U S A* 1998; 95: 13513-8.
28. Cantley LC, Neel BG. New insights into tumor suppression: PTEN suppresses tumor formation by restraining the phosphoinositide 3-kinase/AKT pathway. *Proc Natl Acad Sci U S A* 1999; 96: 4240-5.
29. Dimmeler S, Fleming I, Fisslthaler B, Hermann C, Busse R, Zeiher AM. Activation of nitric oxide synthase in endothelial cells by Akt-dependent phosphorylation. *Nature* 1999; 399: 601-5.
30. Fulton D, Gratton JP, McCabe TJ, Fontana J, Fujio Y, Walsh K, Franke TF, Papapetropoulos A, Sessa WC. Regulation of endothelium-derived nitric oxide production by the protein kinase Akt. *Nature* 1999; 399: 597-601.

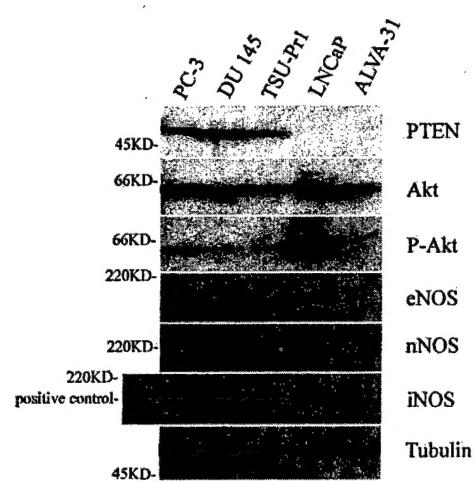
31. Rees DD, Palmer RM, Schulz R, Hodson HF, Moncada S. Characterization of three inhibitors of endothelial nitric oxide synthase in vitro and in vivo. *Br J Pharmacol* 1990; 101: 746-52.
32. Ashkenazi A, Dixit VM. Apoptosis control by death and decoy receptors. *Curr Opin Cell Biol* 1999; 11: 255-60.
33. Xiao C, Yang BF, Asadi N, Beguinot F, Hao C. Tumor necrosis factor-related apoptosis-inducing ligand-induced death-inducing signaling complex and its modulation by c-FLIP and PED/PEA-15 in glioma cells. *J Biol Chem* 2002; 277: 25020-5.
34. Scaffidi C, Fulda S, Srinivasan A, Friesen C, Li F, Tomaselli KJ, Debatin KM, Krammer PH, Peter ME. Two CD95 (APO-1/Fas) signaling pathways. *Embo J* 1998; 17: 1675-87.
35. Deveraux QL, Reed JC. IAP family proteins--suppressors of apoptosis. *Genes Dev* 1999; 13: 239-52.
36. Chung HT, Pae HO, Choi BM, Billiar TR, Kim YM. Nitric oxide as a bioregulator of apoptosis. *Biochem Biophys Res Commun* 2001; 282: 1075-9.
37. Mannick JB, Hausladen A, Liu L, Hess DT, Zeng M, Miao QX, Kane LS, Gow AJ, Stamler JS. Fas-induced caspase denitrosylation. *Science* 1999; 284: 651-4.
38. Kim YM, Kim TH, Chung HT, Talanian RV, Yin XM, Billiar TR. Nitric oxide prevents tumor necrosis factor alpha-induced rat hepatocyte apoptosis by the interruption of mitochondrial apoptotic signaling through S-nitrosylation of caspase-8. *Hepatology* 2000; 32: 770-8.
39. Kim YM, de Vera ME, Watkins SC, Billiar TR. Nitric oxide protects cultured rat hepatocytes from tumor necrosis factor-alpha-induced apoptosis by inducing heat shock protein 70 expression. *J Biol Chem* 1997; 272: 1402-11.
40. Genaro AM, Hortelano S, Alvarez A, Martinez C, Bosca L. Splenic B lymphocyte programmed cell death is prevented by nitric oxide release through mechanisms involving sustained Bcl-2 levels. *J Clin Invest* 1995; 95: 1884-90.

A.

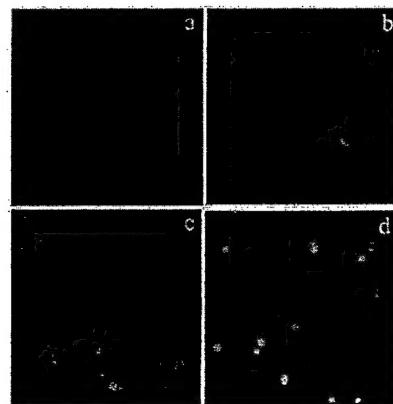


B.

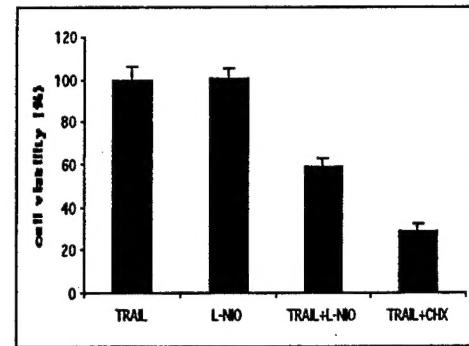




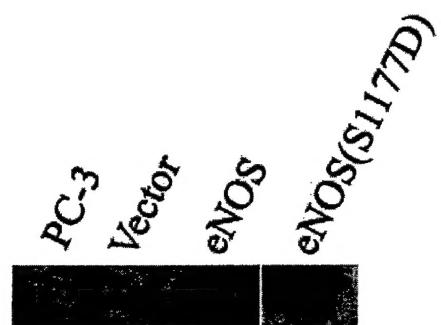
A.



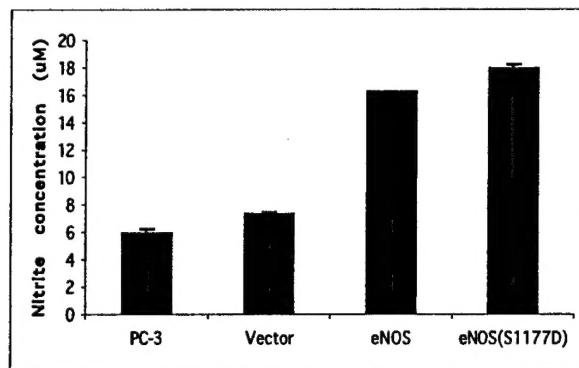
B.



A.



B.



C.

